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THESIS

A SYSTEMS APPROACH TO MANAGING LOW-SCOPE GROWTH-WORK IN NEW CONSTRUCTION SHIPBUILDING

by

Mark Ryan Glass

September 2018

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The goal of this study is to determine if a set of heuristics can be used as a decision-making tool to effectively determine what low-scope growth-work needs to be targeted for execution early in the construction cycle of a new naval ship. This study analyzes growth-work that is not incorporated into the base contract with a formal engineering change proposal, but rather a less-formal waterfront change process where the logistics and engineering products are updated after the delivery of the ship. This study shows why some growth-work is significantly more expensive or disruptive to the crew if completed after delivery of the ship. Growth-work is realized during the long construction cycle due to technology changes, lessons learned from previous hulls, fleet requirement changes, and contract requirement gaps. Since not all of the growth-work can be incorporated during the period of performance of the base contract, this study lays out a heuristics-based systems approach to managing low-scope growth-work in new construction shipbuilding. This study shows which heuristics are effective to target growth-work that will drive cost and crew disruption if executed after the delivery of the ship. Finally, this study models this approach using cam DEFinition for Function Modeling (IDEF0) diagrams. These models provide a framework for use by other program offices.

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A SYSTEMS APPROACH TO MANAGING LOW-SCOPE GROWTH-WORK IN NEW CONSTRUCTION SHIPBUILDING

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Submitted in partial fulfillment of the
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ABSTRACT

The goal of this study is to determine if a set of heuristics can be used as a decision-making tool to effectively determine what low-scope growth-work needs to be targeted for execution early in the construction cycle of a new naval ship. This study analyzes growth-work that is not incorporated into the base contract with a formal engineering change proposal, but rather a less-formal waterfront change process where the logistics and engineering products are updated after the delivery of the ship. This study shows why some growth-work is significantly more expensive or disruptive to the crew if completed after delivery of the ship. Growth-work is realized during the long construction cycle due to technology changes, lessons learned from previous hulls, fleet requirement changes, and contract requirement gaps. Since not all of the growth-work can be incorporated during the period of performance of the base contract, this study lays out a heuristics-based systems approach to managing low-scope growth-work in new construction shipbuilding. This study shows which heuristics are effective to target growth-work that will drive cost and crew disruption if executed after the delivery of the ship. Finally, this study models this approach using cam DEFinition for Function Modeling (IDEF0) diagrams. These models provide a framework for use by other program offices.

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LIST OF ACRONYMS AND ABBREVIATIONS

AT	acceptance trials
BT	builder’s trials
CCB	Change Control Board
CMA	crew move board
DoD	Department of Defense
DoN	Department of the Navy
ECP	engineering change proposal
EEBD	emergency escape breathing device
FCT	final contract trials
FOA	Fitting-Out Availability
GAO	Government Accountability Office
GSS	General Specifications for Ships
ICAM	integrated computer aided manufacturing
IDEF	Icam DEFinition for Function Modeling
ILS	integrated logistics support
INSURV	Board of Inspection and Survey
OWLD	Obligated Work Limiting Date
PDA	Post-Delivery Availability
PSA	Post-Shakedown Availability
SCN	Ships Construction, Navy
SUPSHIP	Supervisor of Shipbuilding

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EXECUTIVE SUMMARY

The acquisition of a United States Navy ship typically takes several years with large, complex ships like aircraft carriers and amphibious assault ships needing as much as six to nine years. During this time, technology changes, lessons are learned from previous hulls, fleet requirements changes, and contract requirement gaps are realized. All of this creates growth-work. Typically, the identified growth-work is planned for completion after ship delivery unless it is safety or performance related. Safety and performance growth-work is generally rolled into the base contract through the use of an engineering change proposal (ECP) (Department of Defense [DoD] 2001, 6–12). ECPs often carry large price tags regardless of scope due to the engineering and logistics efforts required. This makes ECPs cost prohibitive for use in low-scope growth-work. There is a process in use by some programs to contract low-scope growth-work during ship construction prior to delivery by way of a waterfront change (WFC) process, which does not go through a vigorous engineering effort to update drawings, and Integrated Logistics Support (ILS) products with the prime contractor. WFCs wait until after delivery to complete the required ILS updates at a lower cost, so their use is often avoided. Unfortunately, waiting to complete some low-scope growth-work significantly increases costs and causes undue disruption to a certifying crew.

According to a 2010 Government Accountability Office (GAO) report, there is a heuristic in use by shipyards called the "1-3-8 rule of thumb" (Martin 2010, 7). The heuristic states, "work that takes 1 hour to complete in a workshop, takes 3 hours to complete once the steel panels have been welded into units (sometimes called modules), and 8 hours to complete after a block has been erected or after the ship has been launched" (Martin 2010, 8). The report further states, "these numbers of hours tend to increase as the complexity and outfitting density of a ship increase" (Martin 2010, 8). The longer the delay to incorporate a change, the more the change will cost. Why is low-scope growth-work, which is realized early in construction, planned for execution after the ship is complete? This is a complicated question to answer. First, shipbuilders have tight construction schedules and an incredibly complex scope of work. Adding any more scope midstream could affect the already fragile schedule. Second, even small changes influence the ILS products and configuration of the ship. Unless

there is a process to account for those changes prior to crew move aboard (CMA), one introduces increased risk to safe and/or efficient operation of equipment by the crew. Third, the cost of ILS and engineering changes is less expensive after delivery.

This research demonstrates that the use of a set of heuristics to guide the decision-making process on when to execute a change can drive down cost and significantly decrease disruption to the crew. Executing all known growth within the period of performance of the base contract is not possible, so this research lays out a process to determine which changes should be targeted for early execution and which changes can or must wait until after delivery. The heuristics proven to work when analyzing growth-work are as follows:

1. Focus on Hot-work

Hot-work is any operation that produces enough heat to burn paint and includes welding, grinding, and plasma cutting. Hot-work occurs in multiple compartments and increases cost if completed after the compartment is finalized.

2. Ensure the Systems Work

Growth-work items that influence one of the ship's many systems must be targeted for completion at the appropriate time. Unlike hot-work items, growth-work affecting a system may not need to be executed early in construction, but must be planned for completion prior to that system being ready for testing.

3. Identify Disruptive Changes

After delivery, the crew's mission is to get certified to operate the ship. The program office and project office must critically look at each growth-work item and access its impact to the crew.

4. Stay Away from the Captain

The commanding officer, executive officer, and department heads of a new ship and a new crew have limitless things about which to worry. Do not postpone any work item that will directly affect the key leaders of the ship after delivery.

5. Help the Shipbuilder

The shipbuilder is building the ship to the specifications in the contract. If the contract is missing a key requirement that will negatively affect their INSURV score or reputation to the crew or the fleet, execute the work early in construction.

These heuristics were used to analyze the known growth-work early in the construction schedule of a ship. This resulted in a plan that would execute the known growth-work when it was the most cost effective and least disruptive to the crew. The team executed the plan and saved the program office over $1.7M on 70 changes with identical scope as the previous ship. While no objective quantification of crew disruption was available, highly disruptive changes were executed early and crew disruption appeared to have been minimized.

Finally, the change process was modeled using IDEF0 (Icam DEFinition for Function Modeling) diagrams. These are designed to model the activities of an organization or system and the exchanges between these activities (Marca and McGowan 2006, 13). The IDEF0 diagram uses standardized notation and language to describe the change process in progressively higher levels of detail ensuring that project and program offices understand the entirety of this approach and its impacts

This thesis demonstrates that by applying a heuristics-based systems approach to managing the low-scope growth-work in new construction shipbuilding, the program office can save millions of dollars while allowing the new crew to focus on training and certification as they prepare to sail the ship away for the first time. Ultimately, this thesis demonstrates why 70 identical growth-work jobs cost $3.37M and caused massive disruption to the crew on one ship and cost less than $1.59M and caused minimal disruption to the crew on another ship.

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I. INTRODUCTION

A. BACKGROUND

The acquisition of a United States Navy ship typically lasts several years with large, complex ships like aircraft carriers and amphibious assault ships taking as much as six to nine years. During this time, technology changes, lessons learned from previous hulls, fleet requirements changes, and contract requirement gaps are realized. All of this creates growth-work. Growth-work is defined as any change to the ship outside the scope of the base contract. Processes are in place to ensure that the growth-work is tracked and completed before the ship reaches Obligated Work Limiting Date (OWLD), which is the end of ship's construction, Navy (SCN) funding and the point at which the fleet becomes financially responsible for the ship (Department of the Navy [DoN] 2014, 5). Typically, the identified growth-work is planned for completion after ship delivery unless it is safety or performance related. Safety and performance growth-work is generally rolled into the base contract through the use of an engineering change proposal (ECP) (Department of Defense [DoD] 2001, 6–12). Typically, ECPs carry large price tags, regardless of scope, due to the engineering and logistics efforts required. This makes ECPs cost prohibitive for use in low-scope growth-work. Some programs use a process to contract low-scope growth-work during ship construction prior to delivery by way of a waterfront change (WFC) process. The use of WFCs is not required and its process for implementation varies widely from program to program. WFCs do not go through the vigorous engineering effort to update drawings and Integrated Logistics Support (ILS) products with the prime contractor, rather these products are updated after delivery, so their use is often avoided.

When the ship is delivered to the Navy, it is essentially complete with the exception of the growth-work that was not captured in the base contract. In order for the program office to turn over a fully capable ship to the fleet, there are several repair availabilities after delivery of a ship to complete growth-work prior to OWLD (DoN 2014, 1). "An availability is defined as the time during which a U.S. naval warship is made available to a maintenance activity for the accomplishment of maintenance," alterations, and modernizations (Caprio and Leszczynski 2012, 7). According to a 2010 Government

Accountability Office (GAO) report, there is a heuristic in use by shipyards called the "1-3-8 rule of thumb" (Martin 2010, 7). The heuristic states, "work that takes 1 hour to complete in a workshop, takes 3 hours to complete once the steel panels have been welded into units (sometimes called modules), and 8 hours to complete after a block has been erected or after the ship has been launched" (Martin 2010, 8). The report further states, "these numbers of hours tend to increase as the complexity and outfitting density of a ship increase" (Martin 2010, 8). Knowing this, why is low-scope growth-work, that realized early in construction, planned for execution after the ship is complete? This is a complicated question to answer. First, shipbuilders have tight construction schedules and an incredibly complex scope of work. Adding any more scope midstream could affect the already fragile schedule. Second, even small changes influence the ILS products and configuration of the ship. Without a process to account for those changes prior to crew move aboard (CMA), increased risk is introduced to the safe and/or efficient operation of equipment by the crew. Third, the cost of ILS and engineering changes is significantly less expensive after delivery. Finally, "We've always done it that way." Historically, program offices complete low-scope growth-work post-delivery, so those processes and procedures are already in place.

This thesis demonstrates that by applying a heuristics-based systems approach to managing the low-scope growth-work in new construction shipbuilding, the program office can save millions of dollars, while allowing the new crew to focus on training and certification in preparation for delivery. Ultimately, this thesis shows why 70 identical growth-work jobs can cost $3.37M and massive disruption to the crew on one ship but less than $1.59M with minimal disruption to the crew on another ship.

B. RESEARCH QUESTIONS

This thesis explores the following research questions:

1. What is the best way to identify and execute low-scope growth-work in new construction shipbuilding?

The goal of this study is to find a process for growth-work execution that is the most efficient from a monetary perspective for project office and a man-hour cost perspective to a new crew. Timing is critical since the growth-work must be accomplished before the ship becomes a fleet asset.

2. Can heuristics be used effectively to identify which changes should be executed early in construction and which changes can be completed after completion? If so, what are the right heuristics to use?

As discussed previously, there is a heuristic used by shipbuilders called "1-3-8" rule of thumb. This heuristic can be used to identify when growth-work should be accomplished from a cost perspective. Cost is not the only thing to consider. What heuristics can be used to identify when growth-work should be done from a crew disruption perspective? With all of the stakeholders involved in the growth-work execution process, identifying the right heuristics to apply is imperative.

3. What are the constraints to completing growth-work during the period of performance of the construction contract?

The shipbuilder has a large and complex scope of work that is difficult to finish within the contractually obligated timeframe. Adding additional scope via changes, even low-scope changes, will disrupt the shipbuilder. Identifying all of these constraints and inputting them into the process will allow the stakeholders to understand the trade space.

4. What data needs to be captured and analyzed to prove the improved process works?

All process changes must be validated to ensure that purpose of the changes is realized and that the change has not caused unacceptable collateral damage. The correct data must be identified and captured to claim success or failure of the process change.

The author of this study is the Production Manager for a shipbuilding Major Defense Acquisition Program working for the Supervisor of Shipbuilding, Gulf Coast. The author provides construction oversight for all phases of ship construction. Additionally, the author plans, coordinates, and implements the growth-work changes with the prime contractor. The author has been serving in this capacity for nearly five years.

C. BENEFIT OF STUDY

This research provides benefits to multiple stakeholders in the shipbuilding process. An improved process for the execution of growth-work will benefit the following stakeholders.

1. The Warfighter

If the right growth-work is targeted for completion early in construction, the warfighter will be able to focus more time on the training and certification after CMA and before sailing away. Additionally, fewer systems will need to be taken out of commission to conduct work. This allows the crew more opportunity to operate and train on systems in preparation for the certifications required to sail the ship.

2. The Program Office

The program office is able to execute the right growth-work earlier. In most cases, this will result in the change costing significantly less. The program office can use the savings on unanticipated additional growth-work or cost overruns by the prime contractor. Overall, it gives the program office more flexibility and agility with their tight budgets.

3. The Shipbuilder

The shipbuilder is only responsible for the scope of work in the base contract. However, at acceptance trials (AT) the ship is ultimately inspected and graded by the Board of Inspection and Survey (INSURV). The INSURV inspectors, grade the ship to fleet requirements to validate that the ship is ready to be turned over to the Navy (DoN 2014, 6). As discussed previously, there is often a delta between the base contract and fleet requirements. The ship's INSURV score can be negatively impacted by government responsible work. By taking on growth-work early, the shipbuilder can mitigate its risk of a low INSURV score that may not be its fault but would be perceived that way.

D. ORGANIZATION OF THESIS

Chapter II: The "1-3-8" Rule Decomposed: This chapter will breakdown why changes become more complex and expensive as the ship moves through the various stages of construction. A seemingly insignificant change, welding a small clip to the deck, is explored to illustrate the impacts when performed in a finished shipboard compartment versus an unfinished compartment. Finally, it will explore the influence on the crew if the example is completed after CMA.

Chapter III: Application of the Systems Approach: This chapter will identify the heuristics to be used to target growth-work that should be executed early in construction and delay growth-work that should be moved to after delivery of the ship. This chapter will analyze the costs of identical work performed on the same class of ship but during different phases of the shipbuilding construction phases. It will provide validation that the process change was both needed and effective.

Chapter IV: IDEF Method to Modeling the Systems Approach to Low-Scope Change Management: This chapter will model the process using IDEF (Icam DEFinition for Function Modeling) diagrams to model the activities of organizations and the exchanges between these activities. It will provide a framework that can be tailored to other shipbuilding programs.

Chapter V: Conclusions and Recommendations: This chapter summarizes the research conducted in this thesis and the results. It also provides recommendations for the application of the results of this research. Finally, it provides areas that were not fully explored by this thesis and are worthy of further research.

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II. THE “1-3-8” RULE DECOMPOSED

A. BACKGROUND

Again, heuristic of the Shipbuilder’s “1-3-8” rule of thumb states, “work that takes 1 hour to complete in a workshop, takes 3 hours to complete once the steel panels have been welded into units (sometimes called modules), and 8 hours to complete after a block has been erected or after the ship has been launched” (Martin 2010, 7). This is based on the fact that the most efficient time to complete a given task is at the earliest stage of construction because there is less potential hindrance to any work already accomplished. The earliest stage of construction for the ship occurs at the shop level. At the shop, the tools, plans, machinery, and utilities that an employee needs to accomplish the task are readily available and the work area is free from obstruction. Additionally, the work can be accomplished in a controlled environment where supervisors can observe and correct deficiencies before they result in expensive rework.

As construction continues, the work on a particular system becomes more difficult as the system becomes part of a module and is moved into an outfitting hall. The space in the outfitting hall is less efficient than on the open shop floor because of increased obstruction from adjacent systems and access limitations for workers. Units create enclosed compartments where supplemental ventilation is needed. In order to weld inside the unit, gas lines have to be snaked through the unit to the work area. There is no climate control, so performance and sometimes quality can be affected by the heat, wind, and rain. This reduced efficiency results in the same hour of work that could have been accomplished in the shop taking three hours to complete in the outfitting hall.

Efficiency is reduced even more once the module is moved from the outfitting hall and erected on the hull of the ship. Access is further reduced, tools become more difficult to transport up and down ladders, the units are open to the weather, and an increasing number of systems further limits access and movement. Ventilation and gas lines are still needed, but they are now longer and much more difficult to install. At this point, the system being modified has likely already been installed, so to add a change, one is essentially paying to install, remove, and reinstall. The same hour of work that was accomplished in the shop now takes eight hours to complete after erection. The longer one waits to execute a change, the more complicated and expensive that work becomes.

The increased scope and cost involved in a change after a compartment is completed is illustrated in Figure 1. This figure was created based on the author's knowledge of the shipbuilding process. In this example, welding a deck clip early in construction involves simply welding it in place. Conversely, if one waits to weld the clip to the until after delivery, all of the deck material has to be removed in the affected compartment and all of the insulation and paint have to be removed from the overhead in the adjacent compartment. After all of those steps are complete, the clip can be welded to the deck. Finally, after the clip is welded, the decking and insulation have to be repaired. This is a great example of how complexity and cost can increase dramatically by waiting too late to execute work.

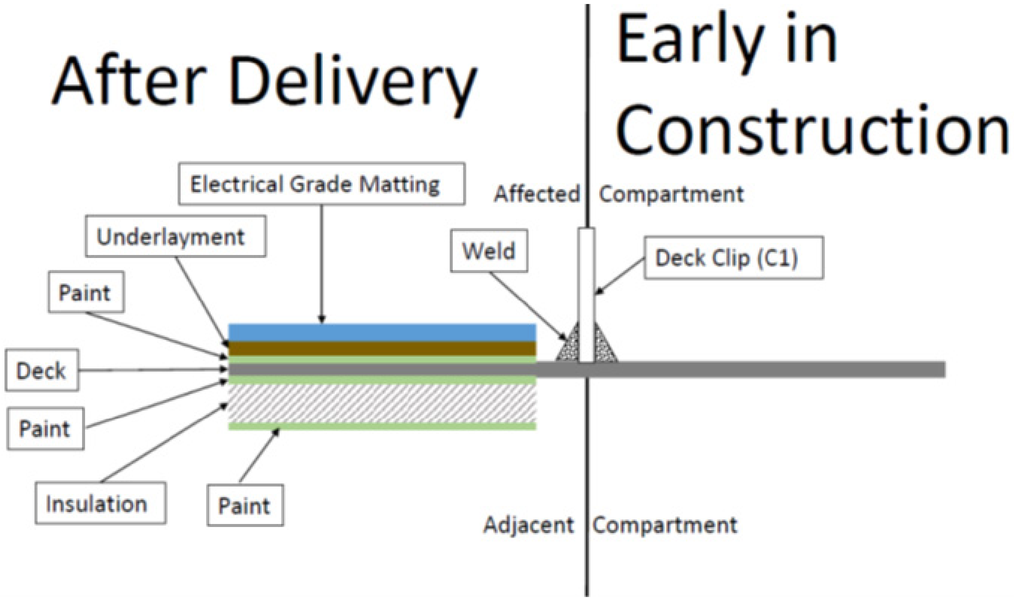


Figure 1. Deck Progression during Construction

B. VALIDATION OF THE “1-3-8” RULE

This section looks at the scope and the cost associated with moving a set of battle helmet racks in the Bridge after the delivery of a ship and compare it to the cost and scope of the same work completed early in construction of a ship. The example demonstrates the “1-3-8” rule by showing the process steps avoided by moving something as simple as a few battle helmet racks early in construction and highlights the opportunities associated with addressing targeted growth-work early in construction. Ultimately, this example illustrates why moving these racks can cost $26,213 on one ship and only $3,715 on another ship.

1. Battle Helmet Rack System

The guidance for the need of a battle helmet rack is given in the General Specifications for Ships (GSS). The GSS section 671 states that “nested stowage racks in accordance with drawing, NAVSEA No. 803–6397394 shall be provided to stow battle helmets for personnel (excluding repair party personnel) assigned on or above the Damage Control Deck at Condition 1 by the ships manning document. They shall be located under cover, adjacent to battle stations” (DoN 1995, section 671).

The battle helmet rack system is extremely simple, made up of only the battle helmet rack and a series of deck clips that weld to the deck to provide support. The two components are attached using nuts and bolts. An example can be seen in Figure 2, which shows the final installation on a nearly complete space much like the left side of Figure 1.

Figure 2. Battle Helmet Racks

2. Scope of Work

For the purpose of this example, the scope of work analyzed is the labor involved with moving the battle helmet racks from one location to another. The battle helmet racks had to be moved because their original location impaired movement in the Bridge. This case study does not analyze the cost of the engineering effort, the logistics effort, or material. While there is cost associated with those efforts, they are the same for both ships. The scope of this work is relocating five battle helmet racks.

3. Relocation after Delivery

After delivery, all of the compartments on the ship are complete. They are fully outfitted, painted, insulated, and have decking installed as seen on the left hand side of

Figure 1. At this point of construction, moving the five battle helmet racks a total of 436 steps. These steps are completed by five craftsmen including a painter, a welder, a deck repairer, a machinist and a welder. The action diagram shown in Figure 3 breaks down all the steps involved in this seemingly simple job. Starting at the top left, the painter removes the previously installed battle helmet racks and prepares the area for the welder. This involves five steps in a loop that repeats 15 times. Once the painter is complete, he informs the welder that the area is ready and the welder cuts the 15 clips off the deck, which can be seen in the bottom right of the action diagram. The painter then prepares the new location for welding. This is shown in the two middle loops on the left side of the action diagram. This involves removing the matting, underlayment and paint form the new area as well as removing the insulation and paint from the overhead in the compartment below the Bridge. The first loop has four steps, while the second loop has two steps and both loops repeat 15 times. Once the new area is ready, the painter informs the welder and the welder welds the clips at the new location as shown on the bottom middle loop of the action diagram. The welder then informs the painter that welding is complete. The painter then prepares the new area for decking and repairs the insulation in the adjacent compartment. The first loop involves two steps, while the second loop involves three steps and both loops are repeated 30 times because the repairs are to the new areas and the areas where the old racks were removed. These two loops are on the top right of the action diagram. The painter then informs the deck installer that the areas are ready for decking. The deck installer repairs the deck in both the new and old location which involves two steps that are repeated 30 times. Finally, once the decks are complete, a machinist installs the battle helmet racks at the new locations. This final loop can be seen on the bottom right of the action diagram and involves two steps that repeat 15 times. This work involved very little material and the final cost of the change was $26,213.

There is also significant disruption to the crew. In order for this work to get accomplished, the crew had to approve the work using their standard work controls process. This involves the routing of an approval sheet through the impacted departments and the duty officer. Additionally, the crew had to validate that temporary ventilation had been run and that the areas were ready for hot-work. Finally, during the work, the crew has to supply two fire watches, which is a capable sailor with a fire extinguisher in the Bridge and the adjacent compartment. Again, this change occurred in the Bridge of the ship during a time when the crew was trying to train and get familiar with the ship. The Bridge of a ship is where the ships movement is controlled by the Officer of the Deck. This is a vital space when trying to train and certify a new crew. The crew has a very short time to get certified to sail. Changes after delivery take away from this effort. The crew typically has to get out of the affected compartments and has strict work controls procedures for work approval. These work control process take the crew's attention off training and drive additional cost to change.

4. Relocation Early in Construction

On the subsequent ship, the movement of the battle helmet racks was accomplished very early in the construction process; the conditions were similar to the right hand side of Figure 1. None of the original work had been accomplished by the shipbuilder. Because none of the base contract work had been accomplished, the team was able to utilized base contract funding to relocate the clips. The cost of the material and the labor was covered under the base contract. Additionally, since the insulation, paint, underlayment, and matting had not yet been installed, it did not need to be removed and reinstalled. Ultimately, the cost of the change paid for the shipbuilder to change the original work bill or guidance to the craftsman. The original guidance attached to the craftsman's work bill was replaced and updated to with the drawing used to relocate the battle helmet racks on the last ship. The action diagram in Figure 4 shows the single step involved in the relocation of the battle helmet racks. Because the change was executed early, the 365-step process, involving five different craftsmen and numerous crew members, was replaced with a one-step process that had no zero disruption to the crew. The final cost of the change was $3,715.

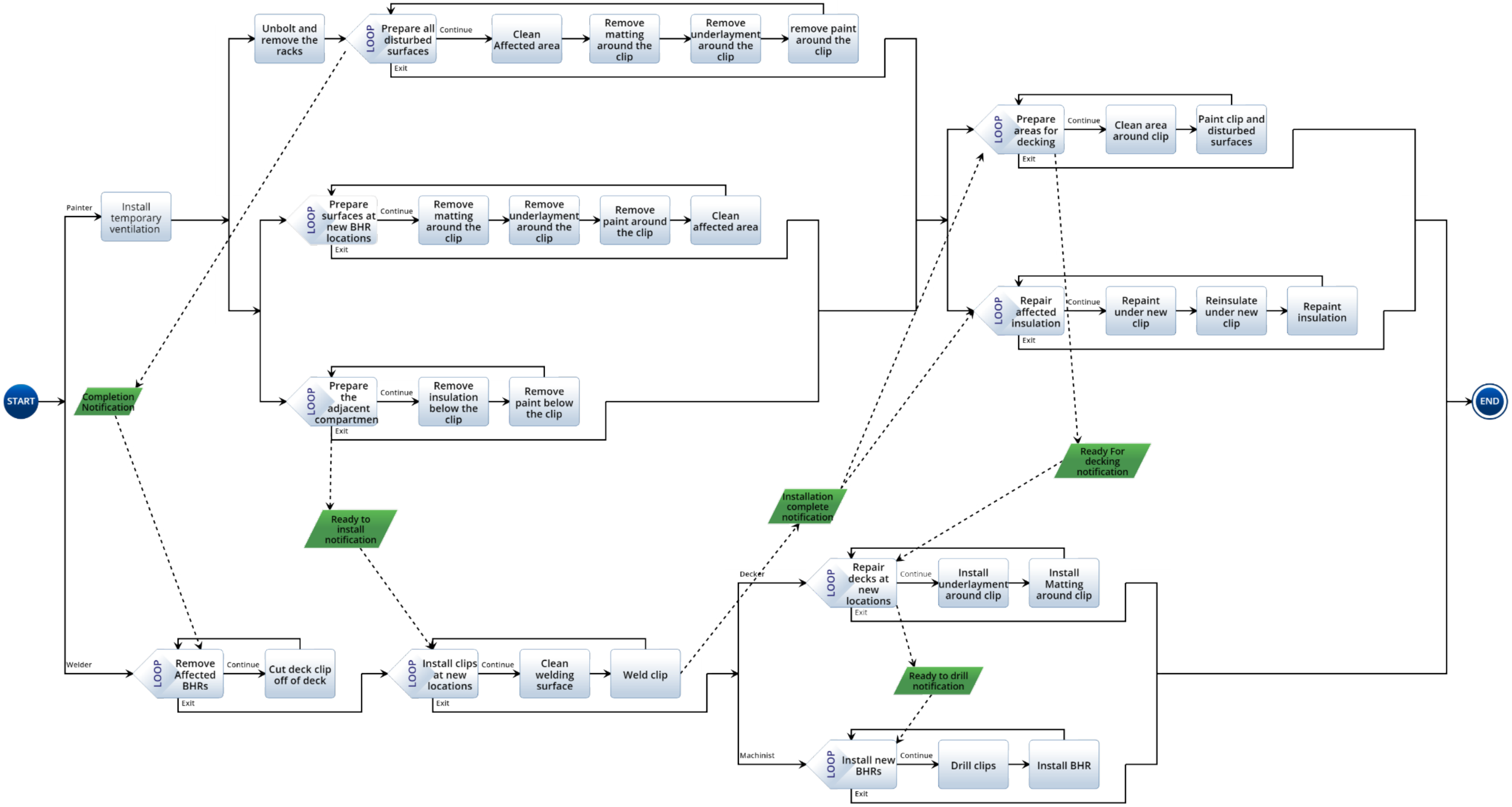


Figure 3. Work Steps after x c Delivery Action Diagram

Figure 4. Work Steps Early in Construction Action Diagram

III. APPLICATION OF THE SYSTEMS APPROACH

A. INTRODUCTION

This chapter identifies the heuristics used to identify growth-work that should be executed early in construction and growth-work that should be delayed until after delivery of the ship. This chapter analyzes the costs of identical work performed on the same class of ship, but at different phases of the shipbuilding construction process and validates that the process change was both needed and effective. For simplicity and of anonymity, the two ships analyzed are named Ship A and Ship B. Ship A performed the majority of the growth-work after delivery, while Ship B used a systems approach to determine when to execute the growth-work based on the set of heuristics identified for this study.

B. BACKGROUND

The Supervisor of Shipbuilding (SUPSHIP) has purview over the construction contracts of new naval ships (DoN 2008, 1–4). Each ship class has a project office co-located with the prime contractor that oversees the contract execution for the program office. One of the many responsibilities of the project office is the execution of changes to the base contract to account for growth-work (DoN 2008, 5–28). Large complex changes, such as upgrading a radar system, go through a rigorous engineering and logistics effort that is both necessary and costly. Low-scope WFCs, such as moving a phone in the commanding officer's (CO) stateroom, does not require much engineering and have a little, if any, ILS impacts.

Early in construction of Ship A, the decision was made to execute the low-scope growth-work after the ship was essentially complete. The decision was based on the "we've always done it that way" rationale and that was when the program office's budget had it planned. Once the ship reached OWLD, the project office went through a process of consolidating and tracking actions based on lessons learned during construction and testing of Ship A. Again, Obligated Work Limiting Date (OWLD), marks the end of Ships Construction, Navy (SCN) funding and the point at which the fleet becomes financially responsible for the ship (Department of the Navy [DoN] 2014, 5). During this effort, the team realized it cost $26,213 to move 5 battle helmet racks. The team decided to dig deeper into low-scope growth-work and develop a plan to decrease the cost of low-scope growth-work on Ship B which was still early in construction. The team gained much needed insight into the costs of all of the post-delivery work items and fully recognized the need to accomplish the identified growth-work earlier.

C. WHY HEURISTICS WERE USED

There were well over 300 post-delivery work items completed on Ship A. Along with 95 WFCs executed prior to delivery. The base contract for ship A was also used on Ship B without including any of Ship A's growth-work. The team could not possibly get the shipbuilder and the program office to allow this much growth-work during the period of performance of the base contract construction. A systematic approach was needed to determine which growth-work should be targeted for execution prior to delivery of Ship B.

A naval warship is filled with systems and compartments that have extreme variations in complexity. Because of this, a change in one compartment or on one system will have different constraints than the exact same change somewhere else. For example, if a speaker needs to be added to both a stateroom and a combat space, the speaker can be added to the stateroom at any time, while the speaker must be added to the combat space prior to it becoming a classified space with cryptographic equipment. Due to the large numbers of variables involved in finding a truly optimal solution, the team decided to use a heuristics-based approach.

Feigenbaum and Feldman, 1963, define a heuristic as follows:

> A heuristic (heuristic rule, heuristic method) is a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solutions in large problem spaces. Heuristics do not guarantee optimal solutions; in fact, they do not guarantee any solution at all; all that can be said for a useful heuristic is that it offers solutions which are good enough most of the time. (Romanycia and Pelletier 1985, 49)

Which of the 300 growth-work items should be completed early? In answering this question that the team developed the heuristics ultimately used to plan out the known growth-work. Since the team had years of experience understanding the true consequences of work items being conducted late and heuristics are just reasoning tools that experts hone over time with experience, it was relatively easy to identify the right heuristics use (Albar and Jetter 2009, 581).

D. HEURISTICS

1. Focus on Hot-Work

Hot-work is any operation conducted that produces enough heat to burn paint and includes activities such as welding, grinding, and plasma cutting. Hot-work can impact multiple compartments and drive up cost if completed after the compartment is completed. As shown in Figures 1 and 4, the simple task of welding a small piece of metal to the deck of a completed compartment results is 30 work steps that would not be needed if the work was accomplished early in construction.

Additionally, hot-work requires temporary ventilation be installed to remove the noxious fumes. The ventilation has to be snaked through the ship and impacts crew movement and further drives up the cost of the work. Hot-work also requires strict work controls. Once the crew moves aboard the ship, they are responsible for the work controls. When they should be training and certifying their new ship, some of the crew is expending valuable time processing work requests for hot-work.

Another consideration involving hot-work is whether the work will impact a large number of the crew since one of the key goals of this process is to limit the impact to ship's crew. For example, a work item that involves welding something to the bulkhead of a small office space can be delayed until after delivery, but the same work item in the crew's mess should be completed early.

Finally, if the hot-work is inside or adjacent to a tank, the work item should be completed as early as possible. The coating system in tanks is extremely expensive to repair. In order to conduct hot-work on a tank, it must be completely emptied and a gas-free engineer must certify the conditions are safe. If the tank holds fuel, the fuel will have to be transferred to another tank, but in some cases, this is not possible and the fuel will have to be discarded which can be extremely costly. Clearly, focusing on work items that involve hot-work is vitally important when planning growth-work execution.

- Application of this Heuristic

The best example of the application of this heuristic was the movement of the battle helmet racks discussed in Chapter II.

2. Ensure the Systems Work

Growth-work items that affect one of the ship's many systems must be targeted for completion at the appropriate time. Unlike hot-work items, growth-work affecting a system may not need to be executed early in construction but must be planned for the completion prior to that system being ready for testing. If the growth-work affects a damage control system, then the work needs to be executed as early as possible because those are the first systems that become operational. Once a damage control system becomes operational, the shipbuilder typically removes the temporary damage control system from the ship, so the growth-work must be accomplished early.

The crew must also be considered. If a system is fully operational without the growth-work being accomplished, but in order to accomplish the work, the system will have to be taken down, this will impact the crew's preparation for certification. Growth-work on systems that will inhibit the ability of the crew to train must be accomplished prior to delivery. The crew needs to operate their systems to become proficient prior to certification for sea.

- Application of this Heuristic

Ship A needed a different type of solenoid valve in its propulsion lube oil system. The system worked without the modification, but the new solenoid valve added vital redundancy in the event of power failure on the ship. In order to replace the solenoid valve, the propulsion lube oil system had to be secured, preventing operation of the propulsion plant. This work item was not complicated and should have only prevented plant operations for a few hours. Unfortunately, the incorrect valve was ordered and the original valve was damaged during removal, making it unusable. The replacement valve took almost four weeks to get delivered. The crew was unable to operate a critical system during preparations for crew certifications for a month.

The scope of this work did not change by completing it early and the cost of the work was nearly same regardless of when it was completed. But by accomplishing this work early on Ship B, the team was able to allow for the inevitable unforeseen issues that come up in shipbuilding without impacting crew training. A four-week disruption while the system is being built, has no impact on the crew or the shipbuilder.

3. Identify Disruptive Changes

After delivery, the crew's mission is to get certified to operate the ship. Each growth-work item must be critically assessed to reduce affecting this requirement. Every work item causes disruptions, but some cause major disruption to a larger number of crewmembers such as work items that secure power or ventilation to multiple compartments. Focus must be placed on those work items that cause disruption to areas critical to the operation of the ship like the engine rooms and combat spaces. These areas need to be free from disruption to allow the crew to train.

- Application of this Heuristic

Additional isolation valves were needed in the chilled water system. To make the system safe to complete this work, a large portion of the air conditioning system was secured making multiple compartments nearly unusable because of the heat affecting a large number of the crew.

The scope of this work did not change and the cost of the work was nearly same regardless of when the work was completed. Nevertheless, by completing the work while the system was being built instead of after acceptance, disruption to the crew was eliminated.

4. Stay Away from the Captain

The commanding officer, executive officer, and department heads of a new ship have limitless concerns and very limited time. The mission of the ship's leadership after delivery is to prepare the crew ready to safely operate a complex warship—an extremely challenging task. Postponing any work item that directly impacts the key leaders of the ship after delivery will reduce training time, efficiency, and effectiveness. The team must target growth-work that affects leadership for completion before delivery of the ship.

- Application of this Heuristic

An intrusion alarm panel needed to be modified and moved in the commanding officer's cabin. The work involved hot-work and required multiple craftsman in cabin and was unusable for a few days requiring the CO to be relocated to another office all while responsible and accountable for certifying a new crew. This disruption was easily avoidable by completing the work item before the crew took over the ship.

5. Help the Shipbuilder

The shipbuilder is only responsible for the scope of work in the base contract. However, at acceptance trials (AT) the ship is ultimately inspected and graded by the Board of Inspection and Survey (INSURV). The INSURV inspectors grade the ship to fleet requirements to validate ship readiness for acceptance by the Navy (DoN 2014, 6). As discussed previously, there is often a difference between the base contract and fleet requirements and this difference can negatively affect the ship's INSURV score even though it is not the fault of the shipbuilder. By taking on growth-work early, the shipbuilder can mitigate its risk of a low INSURV score that may not be their fault but will be perceived that way.

- Application of this Heuristic

The ship specification called for white laminated sheathing in the overhead of all galley spaces. The laminated sheathing had a rough texture that, combined with its color, made it extremely difficult to keep clean. The crew hated it because of the time consumed to keep it clean. Most Navy ships use stainless steel sheathing in the overhead of the galley spaces. The stainless steel sheathing is easy to keep clean. The crew perceived that the shipbuilder was at fault even though the shipbuilder installed exactly what was called-out in the specifications.

Ship A replaced the laminated sheathing after delivery, which was disruptive to the crew, but they were eager to get stainless steel sheathing. The replacement on Ship A involved ripping out all of the previously installed and recently paid for sheathing and replacing it with new sheathing. The effort cost the program office over $700K. On Ship B, the team placed the work item on contract before the required sheathing was purchased by the shipbuilder. The team offset the cost of the more expensive stainless steel sheathing by applying the costs saved by de-scoping the white sheathing from the base contract. Additionally, the team applied the labor set aside in the base contract for the installation and only paid for the additional labor associated with stainless sheathing installation. The early execution resulted in a satisfied and non-disrupted crew and over $640K in savings.

6. Trust Your Team's Instincts and Experience

If a growth-work item just makes sense to accomplish early, accomplish it early. Most team members are going to have unique experiences and lessons learned that can add value to the process of planning growth-work. If an item can be delayed until post-delivery, but should be accomplished early based on the experience from the team or the shipbuilder, plan it early.

- Application of this Heuristic

After delivery, the ship had a commercial marine radar installed as a back-up to the permanently installed surface search radar that is part of the ship's advanced navigation system. A team member with afloat experience knew that the civilian pilots, which helped get the ship into and out of port were familiar with and preferred the commercial radar system. The decision was made to install the commercial radar early on Ship B based on the team member's knowledge and experience.

The scope of work to install the commercial radar after delivery did not involve expensive hot-work, a non-functioning system, crew disruption, impact to the Captain, or help the shipbuilder. The ship was going to be piloted in and out of port at least twice before delivery for sea trials. The early installation of the commercial radar just made good sense. A piloting error, causing a collision or running aground, at builder's or acceptance trials could delay the delivery of the ship significantly.

E. APPLICATION OF THE PROCESS

The team analyzed all of the known growth-work items that were going to be accomplished before delivery of the new ship. The shipbuilder would not possibly accept all of the growth-work because they already had a tight schedule and an extremely complex and difficult scope of work in the base contract. The team applied the heuristics to the know growth-work to determine which of the growth-work items should be targeted for early execution. Figure 5 shows how the team applied the heuristics to each work item to determine when to target the work-item for execution. An explanation of the process follows.

1. Does the work item require hot-work?
2. Is the hot-work on a tank boundary? If yes, execute early
3. Is the hot-work in a location that will impact a large number of crew members, such as the galley or the wardroom? If yes, execute early
4. Does the work item affect a ship's system?
5. Will the system work without completion of the work item? If no, execute early.
6. Is the system a damage control system? If yes, execute early.
7. Will the change impact a large number of crew members, such as shutting down air conditioning in a large area? If yes, execute early.
8. Does the work item impact the ship's commanding officer or the executive officer? if yes, execute early.
9. Will the change benefit the shipbuilder? For example, completion of a work item will prevent the shipbuilder from looking bad due to a government responsible issue. If yes, execute early.
10. Does it just make sense to do the work item early? If yes, execute early.

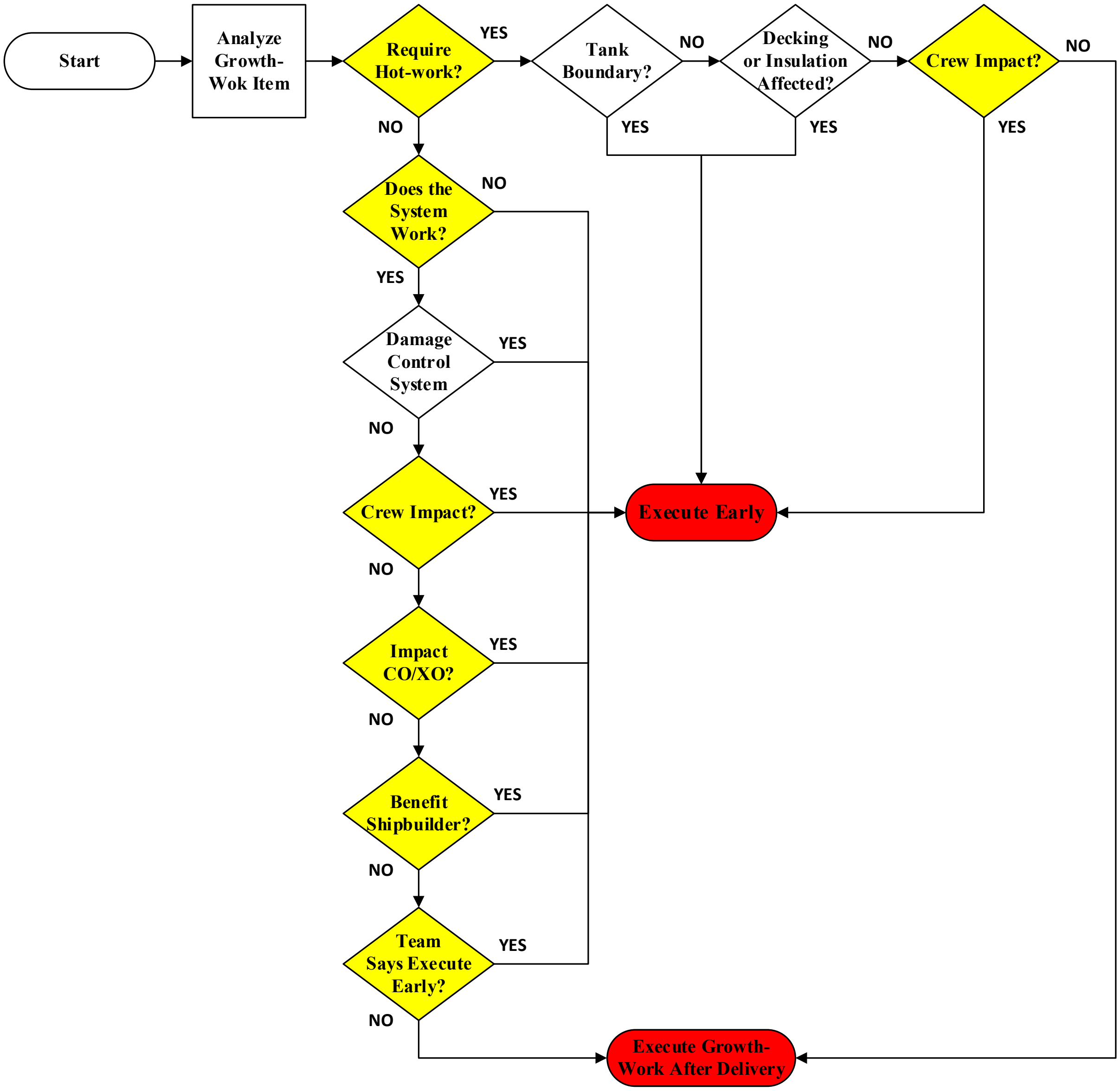


Figure 5. Heuristic Application Flow-Chart

After the application of the heuristics, the team targeted 145 of the over 300 known growth-work items for early execution. Of these 145 work items, two were incorporated into the base contract via an ECP and 11 were not accepted by the shipbuilder. The team then scheduled the 132 remaining work items base for execution based on when they would be most cost effective.

F. RESULTS OF THE PROCESS

Because the contracts of Ship A and Ship B were identical, most of the growth-work required was also identical. This allowed for direct comparison between work items completed early in construction and work items completed close to or after delivery of the ship. Table 1 shows the cost difference between Ship A and Ship B for identical work items. There were many more work items accomplished using this approach, but the 69 work items shown on Table 1 have identical scope. Some work items were changed or combined and could not be used for direct comparison.

Table 1. Cost Difference between Ship A and Ship B

Change Number	**Heuristics Applied (Ship B)**	**Heuristics not Applied (Ship A)**	**Cost Delta**
001	$14,336	$16,980	-$2,644
002	$19,373	$18,409	$964
003	$35,763	$50,989	-$15,226
004	$2,984	$3,496	-$512
005	$3,145	$5,402	-$2,257
006	$17,492	$17,383	$109
008	$67,261	$79,815	-$12,554
009	$1,366	$11,277	-$9,911
010	$19,074	$68,739	-$49,665
011	$100,595	$172,043	-$71,448
012	$46,426	$52,034	-$5,608
013	$13,172	$13,766	-$594
014	$3,715	$26,213	-$22,498
015	$1,393	$13,253	-$11,860
017	$2,002	$2,802	-$800
019	$12,661	$11,112	$1,549
020	$15,504	$13,118	$2,386
021	$10,913	$7,313	$3,600
022	$54,054	$62,633	-$8,579
024	$23,646	$22,823	$823
025	$9,325	$5,820	$3,505
027	$5,743	$24,977	-$19,234

Change Number	Heuristics Applied (Ship B)	Heuristics not Applied (Ship A)	Cost Delta
028	$12,719	$11,367	$1,352
029	$92,198	$87,546	$4,652
030	$1,269	$2,061	-$792
031	$19,728	$19,488	$240
032	$13,721	$249,797	-$236,076
033	$9,429	$16,554	-$7,125
034	$47,641	$50,286	-$2,645
036	$22,865	$74,076	-$51,211
037	$8,575	$13,222	-$4,647
039	$1,294	$14,842	-$13,548
041	$4,210	$18,106	-$13,896
042	$32,424	$60,408	-$27,984
043	$6,675	$40,133	-$33,458
044	$12,667	$150,661	-$137,994
045	$93,571	$738,420	-$644,849
046	$10,827	$12,235	-$1,408
048	$162,336	$375,985	-$213,649
049	-$1,328	$1,485	-$2,813
050	$69,412	$69,419	-$7
051	$11,053	$12,563	-$1,510
052	$47,125	$65,947	-$18,822
056	$4,234	$25,485	-$21,251
065	$5,762	$18,168	-$12,406
066	$5,304	$4,776	$528
069	$16,103	$12,696	$3,407
070	$6,937	$3,424	$3,513
074	$10,256	$14,869	-$4,613
075	$100,618	$122,858	-$22,240
076	$1,437	$11,346	-$9,909
078	$18,922	$25,894	-$6,972
079	$7,467	$4,759	$2,708
080	$38,263	$31,618	$6,645
081	$29,809	$33,737	-$3,928
082	$12,136	$8,526	$3,610
085	$33,749	$82,199	-$48,450
089	$5,748	$7,127	-$1,379

Change Number	Heuristics Applied (Ship B)	Heuristics not Applied (Ship A)	Cost Delta
090	$44,142	$66,758	-$22,616
091	$12,770	$20,382	-$7,612
092	-$11,111	$1,171	-$12,282
093	$15,601	$11,561	$4,040
097	$11,551	$7,962	$3,589
098	$7,335	$5,208	$2,127
106	$10,448	$6,494	$3,954
108	$3,209	$2,545	$664
111	$23,307	$27,745	-$4,438
117	$8,614	$12,649	-$4,035
118	$5,626	$15,000	-$9,374
Total Savings by Applying Heuristics			**-$1,783,364**

1. Analysis of the Results

Overall, it is clear that applying the heuristics to determine when to schedule the growth-work successfully decreased cost and saved over $1.7M dollars. Cost savings is not the only goal of this process; another goal was to decrease disruption to the crew. This section analyzes three changes that dramatically decreased cost and three changes that increased cost but decreased disruption to the crew.

a. Cost Decreases

Change 032 shown on Table 1 resulted in an overall savings of over $236K and decreased disruption to the crew. Change 032 lowered two platforms that were located in the Hanger of the ship. This change had to be accomplished because all aircraft maintenance could not be completed due to the original location of these platforms. This change was targeted for early completion because of the large amount of hot-work required on insulated bulkheads and the impact to the crew if it was completed after delivery. Because this change was put on contract before the platforms were built, the team was able to use base contract funding for the labor and material. On Ship A, the platforms had to be cut off, some material scrapped, and reinstalled at the new locations while the ship’s crew was trying to certify. Since the change on Ship B did not take place after delivery, there was no impact on the crew. This was important because the ship's hanger needs to be free from impact while the crew is trying to train and certify.

Change 048 on Table 1 resulted in a cost savings of over $213K and also decreased disruption to the crew. This change increased the exhaust duct size for one of the sculleries on the ship. A scullery is where the crew washes dishes. This change had to be accomplished because the exhaust duct was undersized in design and causing the space to be extremely hot and humid while in use. The change was put on contract before any of the original ducting was installed so the team was able to use base contract funding for the labor. Additionally, because the duct had not been installed it had not been insulated, so the team was able to utilize some base contract funding for most of the insulation. Execution of this change early also dramatically decreased impact to the crew since it ran through two berthing spaces before exiting the ship. On Ship A, the crew had to deal with active work in what was essentially their bedroom.

Another highly successful change was number 011 on Table 1. This change resulted in a savings of over $71K and also decreased disruption to the crew. This change installed ice machines to the Wardroom Galley and the Bread Room and illustrates the complexity of seemingly simple work. The team was able to use very little of the base contract funding because this change was all new. Adding three ice machines required power circuits, potable water piping, and deck drains to be installed in three new locations.

The power circuits have to be run from a power panel that may require cable to run through multiple compartments. Potable water piping was available in these spaces, but if it is added after the system is complete, regression testing must be conducted and funded to ensure integrity is maintained after the piping is installed.

Installation of three deck drains was by far the most complex part of this job. The deck drain must be cut into the deck and piping run through multiple compartments below the space so it can drain to a waste tank located near the bottom of the ship. The scope of this work was essentially the same, but the savings came from the prevention of regression testing, deck repair, and paint repair. By accomplishing this work early, the disruptions were eliminated and the system could be tested when the rest of the systems were tested for the first time. This one change affected about a dozen compartments and all of the crew that used those compartments. By accomplishing this work early, costs and disruptions are avoided.

b. Cost Increases

The largest cost increase occurred when change number 080 was put on contract. This change cost over $6.6K more than the previous ship. This change installed a piece of calibration equipment to a repair shop. This equipment was flagged by the heuristic "Ensure the Systems Work" because it was required before delivery for crew certification. Because this was a relatively large piece of equipment and the equipment was not on the drawings, the shipbuilder was concerned that they may run into a conflict during construction. To get the shipbuilder to accept the change, the program office had to pay additional engineering labor to update their model. Additionally, because this change happened before delivery and required the installation of a new power circuit, the shipbuilder is required by policy to update their electrical drawings. Had the change been executed post-delivery, this cost would have been lower since it would have been captured in the update to all of the other engineering and ILS products. Even with these cost increases, this work needed to be accomplished early to ensure the crew's certification was not disrupted.

Another example of a change that increased cost was change number 021. Four emergency escape breathing devices (EEBD) had to be relocated. This change was flagged by the heuristic because it is Damage Control and the contract specifications do not match fleet requirements. The contract required the EEBDs to be installed at the egress of the space, so the shipbuilder installed them at the top of the ladder exiting the space. In the fleet, this requirement is interpreted to mean at the egress of the space but within the space. The EEBDs had to be relocated from the top of the ladder, but in another space, to the bottom of the ladder, but within the space they serve. The cost increase also included the shipbuilder updating their model. If the change had not occurred early, the discrepancies would have negatively affected the shipbuilder at acceptance trials and negatively affected the crew when certifying.

The final example of accepting a cost increase to decrease disruption to the crew is change number 025. This change was made to replace a transformer in an aviation repair shop. This repair shop is the primary work area for a large number of crewmembers. The contract showed a different government-furnished furnace than what was actually delivered to the shipbuilder. Since the power requirements differed between the original furnace and the delivered furnace, the transformer needed to be replaced. Because of this, the change was flagged by the heuristic, "Identify Disruptive Changes." Doing this change after delivery would have negatively affected the crew during crew certification, so it was targeted for execution early in construction. The cost increase was due to adding an electrical circuit and the associated costs.

G. CONCLUSIONS

A systems approach to managing low-scope growth-work was successful on many levels. The application of this approach benefited multiple stakeholders.

1. The Warfighter

When the right growth-work is targeted for completion early in construction, the warfighter is able to focus more time on the training and certification after CMA and before sail away. Additionally, because fewer systems will need to be taken down to conduct work, this allows the crew to continue to operate and train on systems in preparation for the certifications required to sail the ship to home port.

The impact of this benefit is hard to quantify, but by applying critical thought and studying the results discussed previously, making crew disruption part of the formula can only help increase the crew's readiness to certify and ultimately safely sail away.

2. The Program Office

The program office was able to execute the right growth-work earlier. In most cases, this resulted in the change costing significantly less. The program office was able to use these savings on unanticipated additional growth-work or cost overruns by the shipbuilder. Overall, it gave the program office more flexibility and agility with their tight budgets. The $1.7M savings could be used to fund additional work items that benefit the crew and ship but may have been cancelled because, while they were needed, they were not absolutely necessary.

3. The Shipbuilder

The shipbuilder cannot go beyond the base contract which puts them at risk for failing to meet known fleet requirements during AT and obtaining a low INSURV score. Identifying and incorporating the needed growth-work early not only improves shipbuilder and crew performance, but demonstrates the government's good faith in ensuring proper attribution of successes and failures of the ship construction process.

IV. IDEF METHOD TO MODELING THE SYSTEMS APPROACH TO LOW-SCOPE CHANGE MANAGEMENT

A. INTRODUCTION

This chapter models how the heuristic based approach to scheduling growth-work, fits into the bigger picture of moving the ship from construction to the fleet. These models perform two major functions. The first major function is to identify all of the steps involved with applying the heuristics-based approach explained in Chapter III. There are many other steps needed to develop an executable growth-work execution plan after the heuristics have been used that have not been discussed previously. For example, there are many constraints like policy and budget that will force work items to be executed when they are not the most efficient. The second major function of these models, is to provide a framework for other Supervisor of Shipbuilding (SUPSHIP) project offices or program offices to tailor to their unique needs to apply this method to their programs and further improve the processes.

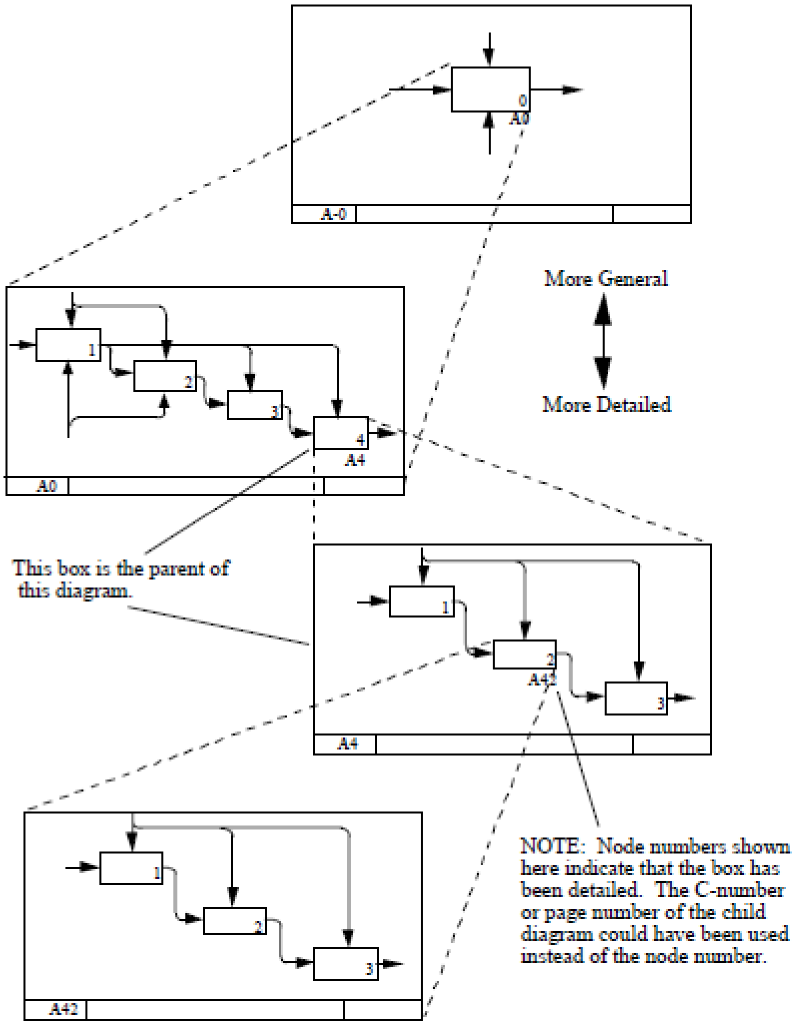
To this point, this study has focused on the benefits of early completion of growth-work and the heuristics used for targeting early execution of the highest value changes. This chapter demonstrates how this approach fits into the overall change management process. As discussed previously, some changes are incorporated into the base contract using an ECP and these changes go through a rigorous engineering and logistic effort to ensure that the engineering drawings and logistics products are updated prior to the delivery of the ship. The program office uses a change control board (CCB) to determine if a needed change is worth the high cost of an ECP (DoN 2004, 6–1). The following models and change management process can be used for all growth-work that has been deemed unworthy of an ECP by the program office.

B. INTRODUCTION TO IDEF AND SADT MODELING

IDEF (Integrated Computer-Aided (ICAM) DEFinition) is an approach to modeling and one of the methods within this approach is IDEF0. Developed by the Air Force's Integrated Computer Aided Manufacturing (ICAM) Task Force in 1973, IDEF0 was derived from a well-established graphical language, the Structured Analysis and

Design Technique (SADT) (Marca and McGowan 2006, xii). IDEF0 is designed to model the activities of an organization or system and the exchanges between these activities.

Effective IDEF0 models help to organize the analysis of a system by identifying what functions are performed (inputs and outputs), what is needed to perform those functions (controls), and who or what is performing those functions (mechanisms) (Marca and McGowan 2006, xiii). The IDEF0 diagram uses standardized notation and language to describe the process. The boxes represent the activities of the process and are named using active verbs like, 'Execute Growth-Work' (Marca and McGowan 2006, 13). These activities are then decomposed into the lower level activities. The decomposition structure of IDEF0 models can be seen in Figure 6. This allows the process to be broken down to the level necessary to be fully modeled without overwhelming the reader with too much information at once



This box is the parent of this diagram.

NOTE: Node numbers shown here indicate that the box has been detailed. The C-number or page number of the child diagram could have been used instead of the node number.

Figure 6. Decomposition Structure.
Source: Department of Commerce (1993).

The arrows represent the artifacts and are named using noun phrases like, "Budget." The arrows connect the activities together and to their interfaces. The arrows are classified as Inputs, Controls, Outputs and Mechanisms (ICOM) (Marca and McGowan 2006, 15). An example of the box and arrow graphics is on Figure 7. The inputs come into the activity from the left and are transformed by activities into outputs and can be in the form of physical outputs and data (Marca and McGowan 2006, 15). The controls constrain the activities and come into the activity on top (Marca and McGowan 2006, 15). In this study, an example of a control is the budget. The program office uses different colors of money before and after delivery and regardless of how much sense it makes to execute growth-work early, if there is no budget, it cannot be executed. Entering at the bottom of the activity, the arrows represent the mechanisms, which is who or what is going to perform the activity (Marca and McGowan 2006, 15). An example of two mechanisms of this study will be the Prime Contractor and the home-port Contractor. The Prime Contractor will execute the work if completed before delivery. The outputs are the result of the activity and leave the activity on the right (Marca and McGowan 2006, 15). In this study, the final output and ultimate goal is growth-work completed.

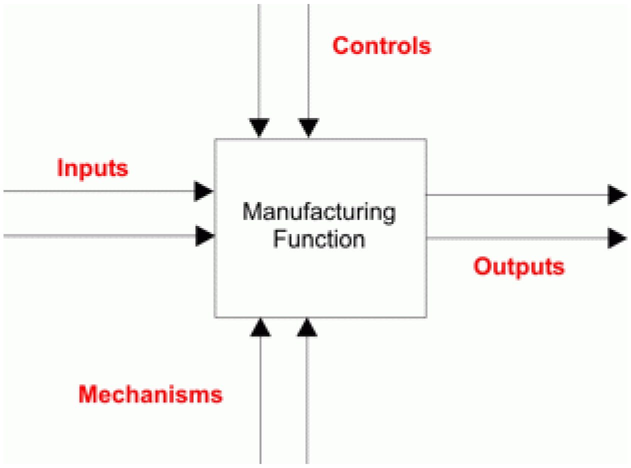


Figure 7. IDEF0 Box and Arrow Graphics. Source: Knowledge Based Systems (n.d.)

This study uses the IDEF modeling method to explain the low-scope growth-work execution process from a systems perspective. The IDEF Model and the ICOM language is appropriate for this study because it is standardized and easily understood. Additionally, because these models show how the process works in progressively higher levels of detail, this will help the decision maker understand the process so the user can execute the process regardless of the shipyard.

C. A0 EXECUTE GROWTH-WORK

The top-level function of this process is to execute or compete all the known growth-work that is realized early in the construction cycle of a ship. This top-level function involves four parent activities that get decomposed into their sub activities. “Execute Growth-Work,” model A0, can be seen in Figure 8. The four activities are “Analyze Growth-Work,” “Execute Pre-Delivery Growth-Work,” “Execute Post-Delivery Growth-Work’” and “Update ILS Products.” Activity A1, “Analyze Growth-work,” is the heuristics based analysis of growth-work discussed in Chapter III with the addition of the controls that can force execution of the growth-work later than preferred. A1 transforms the required growth-work into two outputs, growth-work to be executed pre-delivery and growth-work to be executed post-delivery. Activity A2, “Execute Pre-Delivery Growth-Work” transforms the pre-delivery growth-work required into completed and incomplete pre-delivery growth-work. Activity A3, “Execute Post-Delivery Growth-Work,” transforms all the remaining growth-work into completed post-delivery growth-work. Finally, activity A4, “Update ILS Products,” analyzes the all the previously completed growth-work, updates all the required ILS products, and transforms them into growth-work completed. All of these activities are further decomposed and will be described in detail in the following sections.

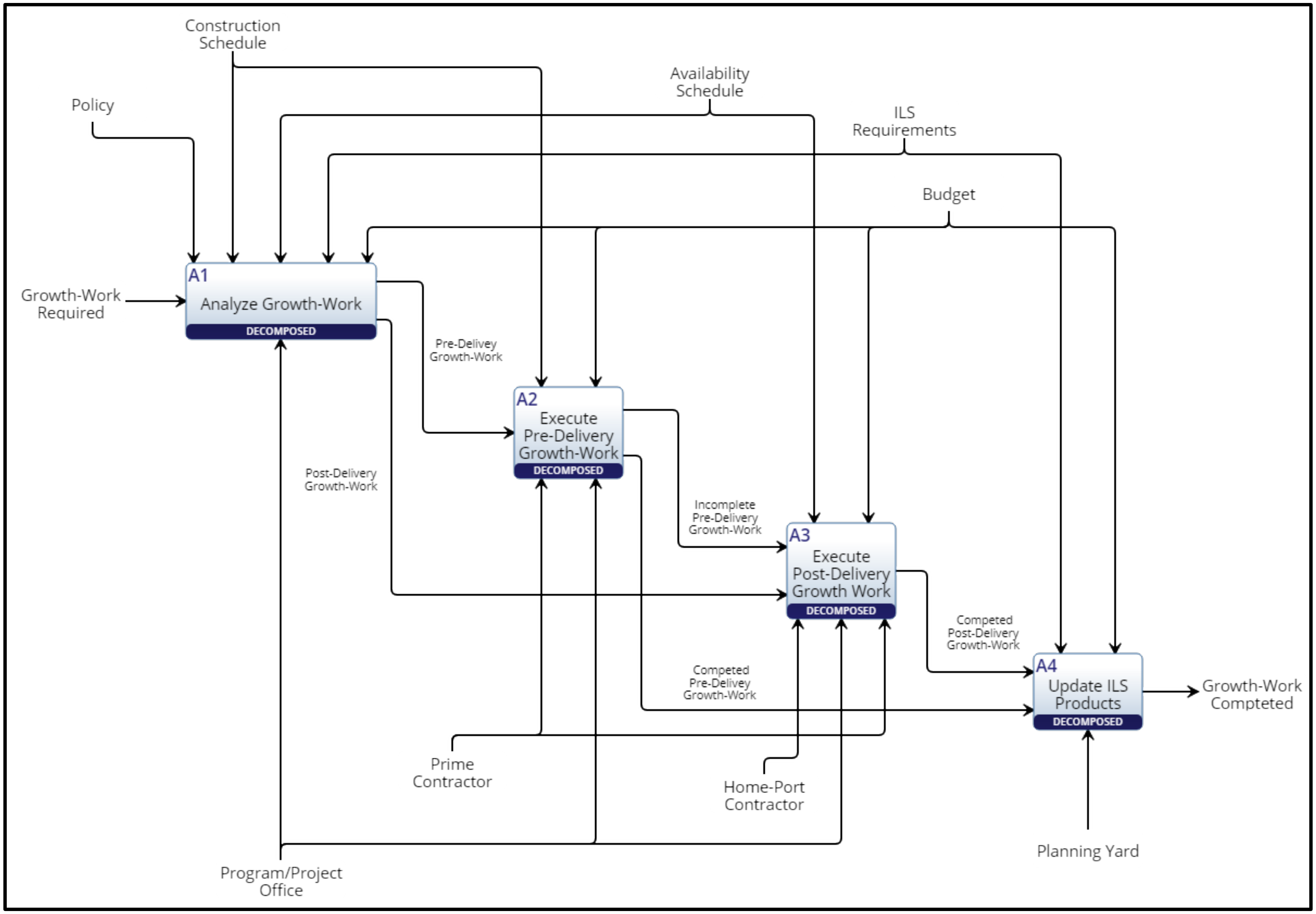


Figure 8. A0 Execute Growth-Work

D. A1 ANALYZE GROWTH-WORK

Activity A1, Analyze Growth-Work, applies the heuristics discussed in Chapter III to the entirety of the known required growth-work and completes the effort of planning the execution of the growth-work by applying applicable constraints. A1 is decomposed into four activities as shown in Figure 9. The activities required to accomplish A1, Analyze Growth-Work, are Apply Heuristics, Estimate Pre-Delivery Scope, Apply Pre-Delivery Budget, and Schedule Growth-Work.

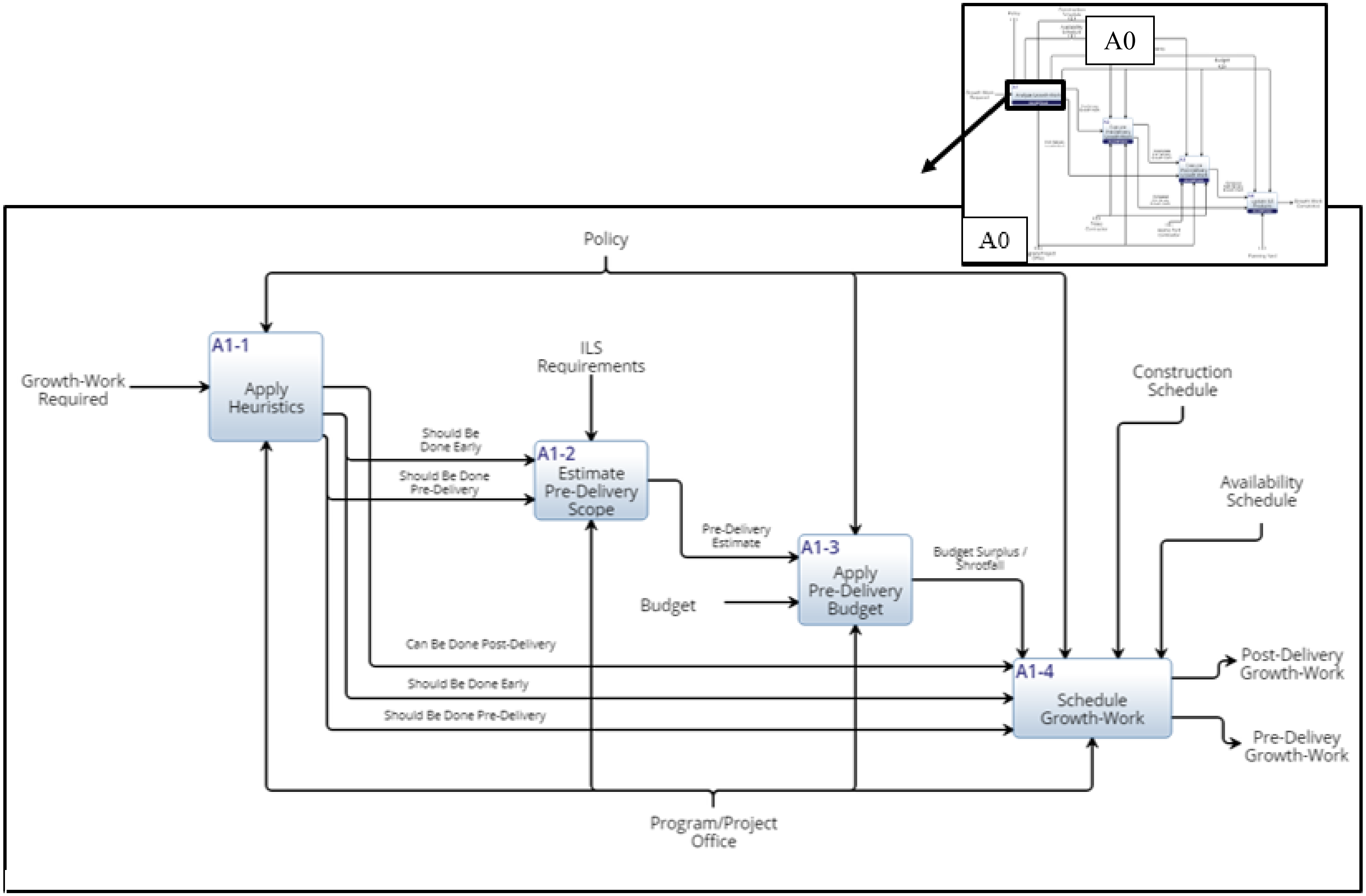


Figure 9. A1 Analyze Growth-Work

1. A1.1 Apply Heuristics

The application of the heuristics to the list of known growth-work is described in Chapter III. What is not discussed in detail in Chapter III are the constraints involved in the decision of when to execute the growth-work. The applicable controls to this activity are policy, construction schedule, and availability schedule.

Both the Navy's and shipbuilder's policies are real constraints that must be considered. Waterfront changes (WFC) follow the requirements laid out in NAVSEAINST 4130.12B, Configuration Management (CM) Policy and Guidance, but do not go through the vigorous engineering and integrated logistics support (ILS) effort involved in an engineering change proposal (ECP). Therefore, SUPSHIP and Program Executive Offices (PEO) develop policies and procedures to ensure that all the required products, (i.e., drawings and logistics) are updated at a later time. One of these policies is the is approval by SUPSHIP waterfront technical authority and an ILS impact review (DoN 2008, 3–48). If during the review, a change is determined to be too complex or would cause unacceptable delayed updates to ILS products, the change will have to be done post-delivery. Additionally, shipbuilders will have their own unique policies on what changes they will allow outside of the ECP process. These policies will be unique to the shipbuilder, but they will typically have constraints on complexity or overall price.

Another constraint of this activity is the construction schedule. Once it is determined which changes should be executed early, these changes should be integrated into the overall construction schedule. If a bracket needs to be welded to the bulkhead of a compartment, the change should not be scheduled until that bulkhead actually exists. All the changes that are planned early in construction should be scheduled when they are the most cost effective.

The last control of this activity is the availability schedule. "An availability is defined as the time during which a U.S. naval warship is made available to a maintenance activity for the accomplishment of maintenance," alterations, and modernizations (Caprio and Leszczynski 2012, 7). As touched on previously, newly constructed naval ships are not 100% complete when the Navy accepts delivery of the ship from the shipbuilder. There is typically remaining shipbuilder responsible work and Government responsible work that was not captured in the base contract. OPNAVINST 4700.8K, Trials, Acceptance, Commissioning, Fitting Out, Shakedown, and Post Shakedown Availability of U.S. Naval Ships Undergoing Construction or Conversion, states the following:

> It is essential that the Navy's shipbuilding and modernization programs deliver to the Commander, U.S. Fleet Forces Command (COMUSFLTFORCOM) and Commander, U.S. Pacific Fleet (COMUSPACFLT) complete ships, free from both contractor and government responsible deficiencies. The ships should be capable of supporting the Navy's mission from the first day of active service. (DoN 2014, 2)

To this end, there are several availabilities scheduled after the delivery of a ship and before the ship becomes an operational fleet asset al.l known growth-work that is scheduled for completion after delivery will need to coincide with the availability schedule.

This activity results in a notional plan for when all of the known growth-work should be done based on the heuristics. The first output is the growth-work that should be done early. This is the work that will increase cost if they are completed late in construction or after delivery. The second output is the growth-work that should be done pre-delivery. This is the work that, while it may not be a cost driver, will cause undue disruption to the crew. Finally, the last output of this activity is the growth-work that can be done post-delivery.

2. A1.2 Estimate Pre-Delivery Scope

All of the growth-work that is planned to be accomplished prior to the delivery of the ship will be given a cost estimate in this activity. This activity is performed by either the local SUPSHIP project office or the program office. During the estimation process, ILS requirements are checked to determine if ILS updates can wait until post-delivery or if the ILS products need to be updated by the prime contractor. If the prime contractor will need to update the ILS products, the cost of the update needs to be captured in the estimate. This activity results in a pre-delivery estimate.

3. A1.3 Apply Pre-Delivery Budget

Once the cost estimate for the pre-delivery scope is determined, it must be compared to the available money in the budget. This activity can be constrained by policy depending on the shipbuilder since some shipbuilders may not allow high dollar value changes without a formal ECP regardless of complexity. The result of this activity is a budget surplus or a budget shortfall. If there is a budget shortfall, the team needs to have discussions with the program office to ensure that they fully understand the value of this process and then work with them to increase funding to cover all items that should be done pre-delivery. In reality, this activity may be an iterative process where the program office funds this effort incrementally based on the execution schedule, but that is beyond the intent of this model. The output of this model will constrain/control the next activity.

4. A1.4 Schedule Growth-Work

This activity will result in a growth-work execution plan. With the exception of the budget information, this activity has the same controls as A1.1, Apply Heuristics. If there is a budget shortfall, the team will need to analyze the growth-work and push the least disruptive and/or costly changes to post-delivery. If there is a budget surplus, the team will have to determine which growth-work previously planned for post-delivery should be moved earlier in construction.

E. OTHER ACTIVITIES

The goal of this study is the application of the heuristics to plan the execution of the growth-work when it is most cost effective and least disruptive. The rest of the models are intended to show how the plan, based on the systems approach, fits into overall execution of the growth-work. Additionally, the models can then be used as a framework for other program offices to tailor to their unique needs and conditions.

1. A2 Execute Pre-Delivery Growth-Work

The A2 model, Figure 10, shows an overview how the pre-delivery growth-work is executed. A2 involves three activities. First, based on the construction schedule the growth-work is planned within the overall construction schedule of the ship. The work is then executed based on that plan. Since the base contract work is the most important to the shipbuilder, some growth-work may not be executed when it is originally planned and some work may slip to post delivery. The team will have to update the plan constantly based on actual execution.

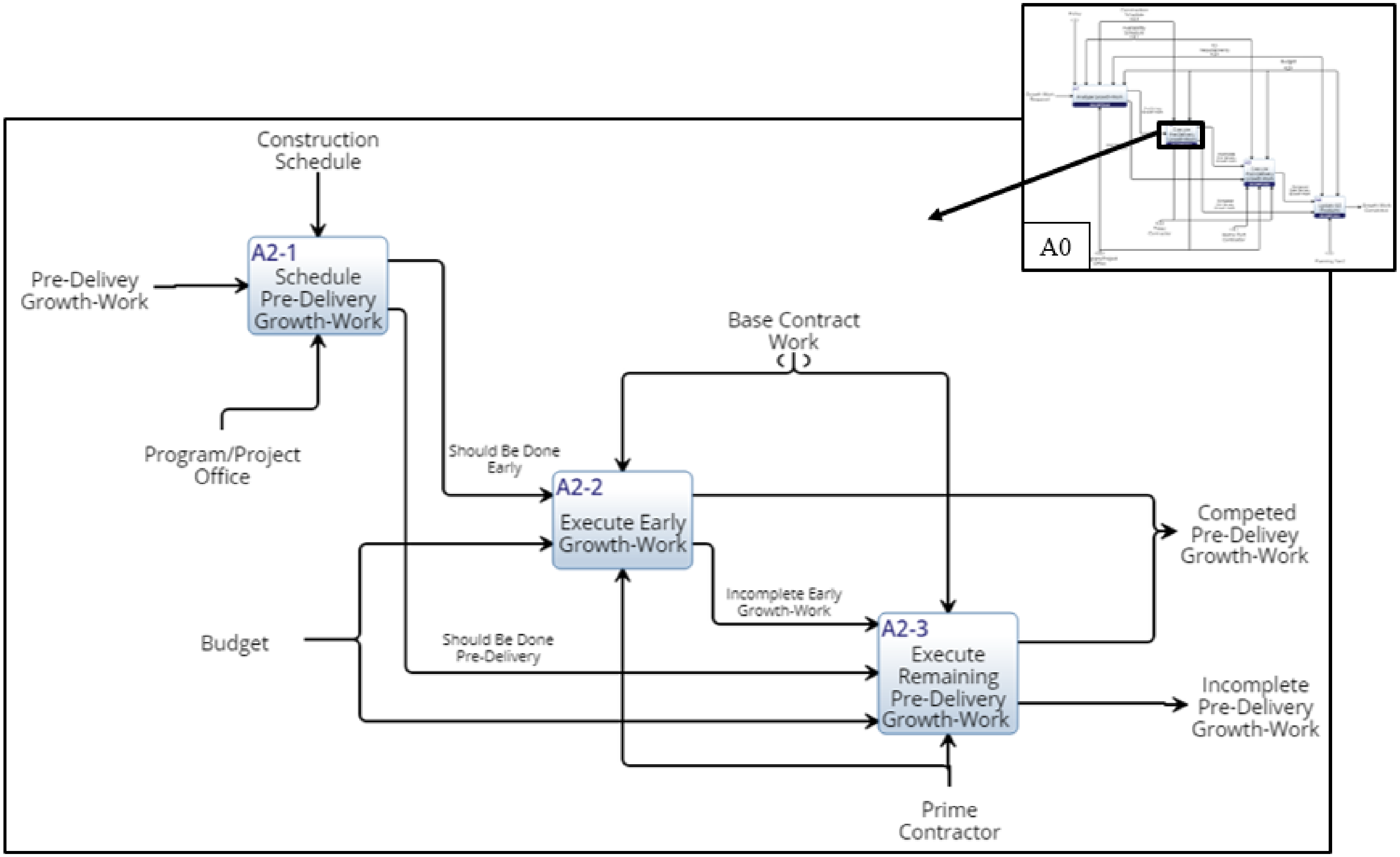


Figure 10. A2 Execute Pre-Delivery Growth-Work

2. A3 Execute Post-Delivery Growth-Work

After delivery, the remaining growth-work is executed in one of the scheduled availabilities. The type of availability and duration will vary based on the ship type and the scope of the remaining work (DoN 2014, 13). The titles and number of availabilities may differ, but the overall approach will be the same as shown on Figure 11. This model shows the post-delivery availabilities the author has experienced. Immediately following delivery, a Post-Delivery Availability (PDA) is conducted by the prime contractor at the original build yard. After the ship sails away, a Fitting-Out Availability (FOA) is completed at the ship's homeport just prior to Final Contract Trials (FCT) and is performed by the homeport contractor. Finally, after FCT and just prior to the ship becoming a fleet asset, a Post Shakedown Availability (PSA) is conducted. The location of the availability will determine the mechanism by which the work gets done. At the end of these activities, all of the required growth-work will either be completed or transferred to the fleet for execution. The execution of the growth-work that is transferred to the fleet is outside the scope of this study. It should also be noted that after delivery, based on the author's experience, growth-work is planned and tracked using the term work-item.

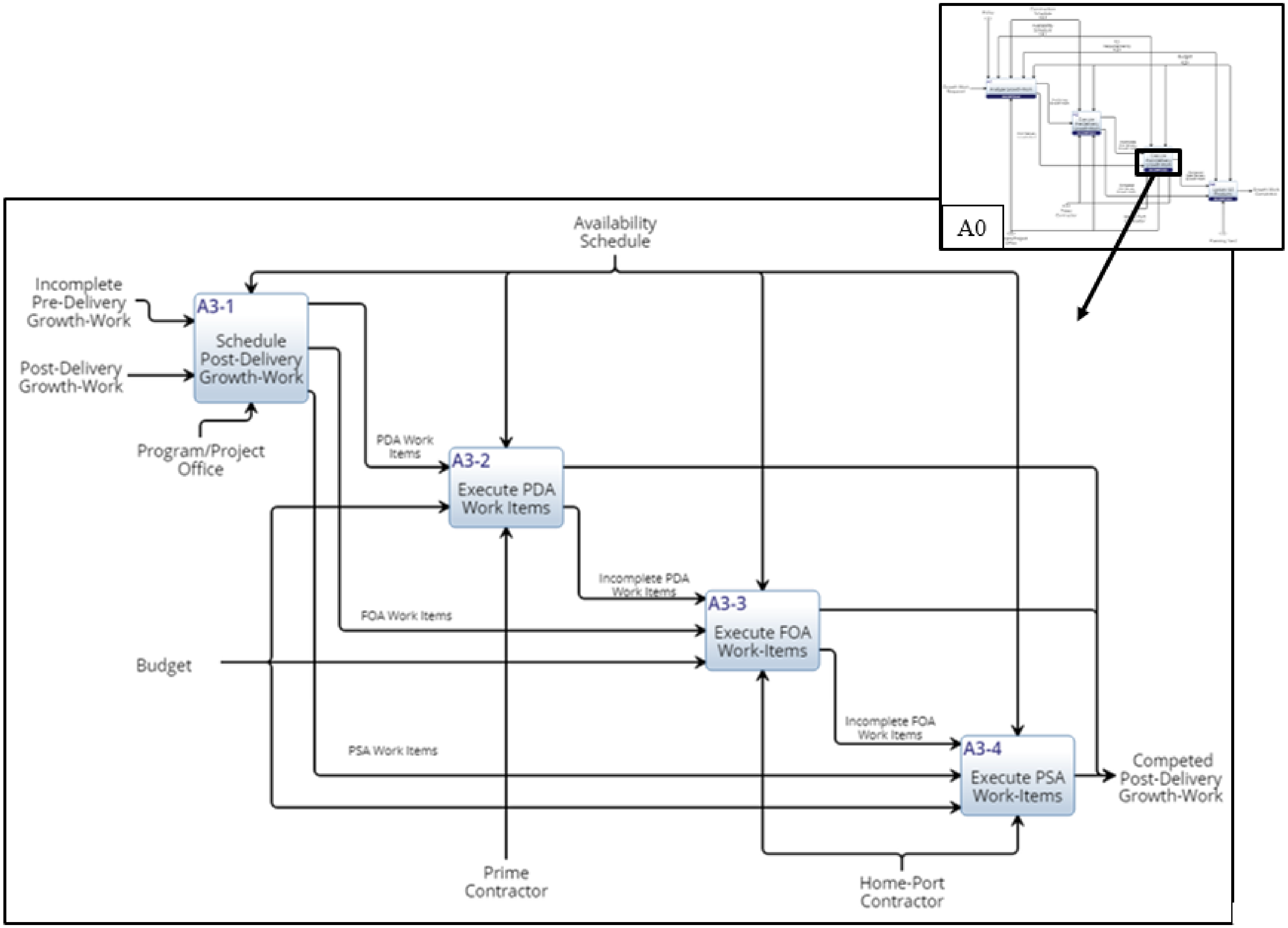


Figure 11. A3 Execute Post-Delivery Growth-Work

3. A4 Update ILS Products

Nearly all of the growth-work will have some sort of ILS footprint associated with it. To ensure that the configuration of the ship is controlled, the ILS products must be updated. These ILS products include, but are not limited to, engineering drawings, technical manuals, allowance equipment list, and allowance parts list. To ensure that the ILS products are updated, the process must include this step. The process that the author has used is shown in Figure 12. Each program office is going to have its own variation of this process. Regardless, the work is not complete until the configuration of the ship is updated to match the actual conditions of the ship.

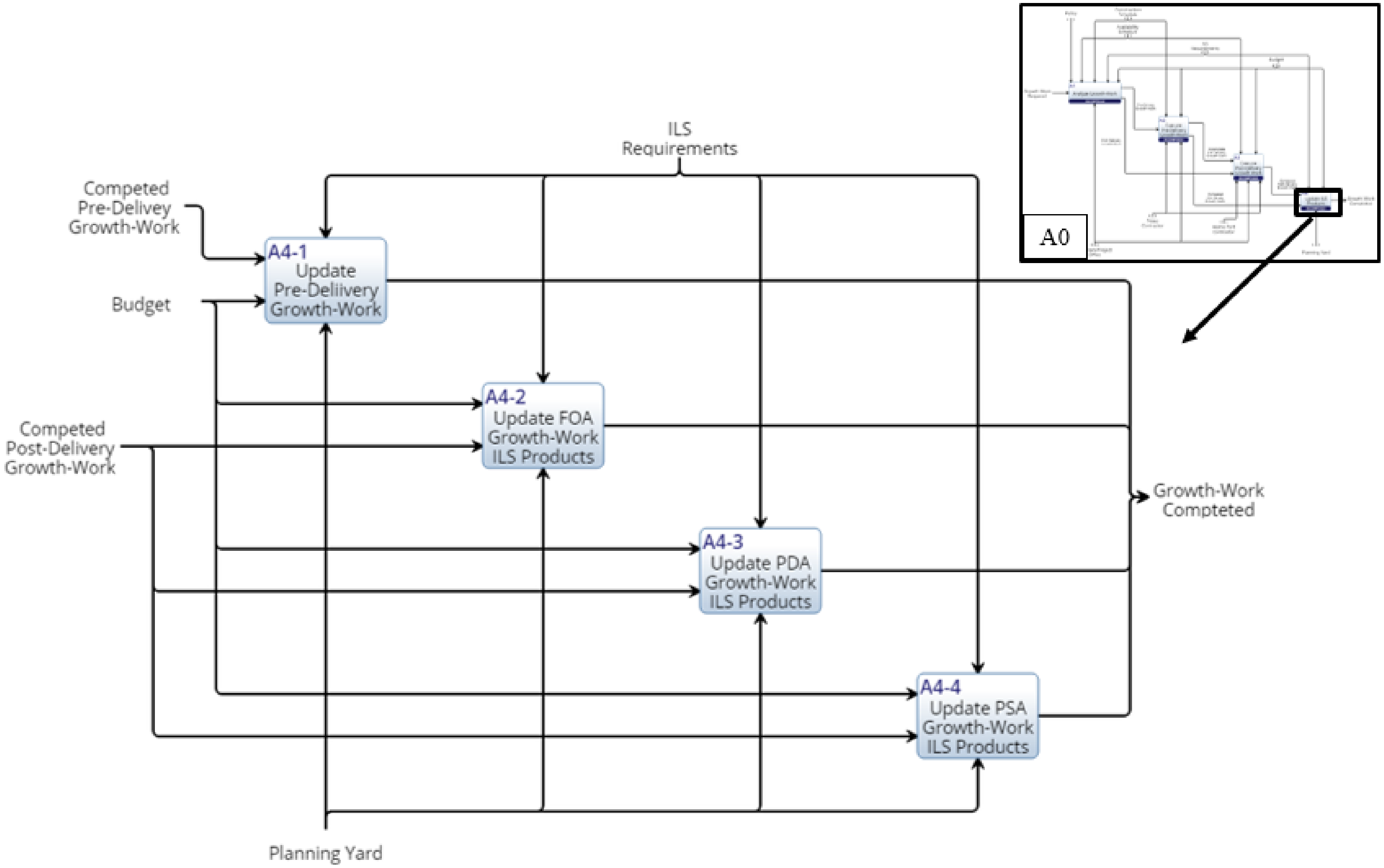


Figure 12. A4 Update ILS Products

F. CONCLUSION

Using the IDEF0 modeling methodology, this chapter modeled how the heuristics-based approach to scheduling growth-work fits into the bigger picture of moving the ship from construction to the fleet. These models performed two major functions. First, they showed all of the steps involved with applying the heuristics-based approach explained in Chapter III. The model showed the many other steps needed to develop an executable growth-work execution plan after the heuristics have been used to determine when the work should be done. Many constraints such as policy and budget may force work items to be executed when they are not the most efficient. Secondly, the model provided a framework for other SUPSHIPS or program offices to tailor this method to their programs' unique needs and further improve the process.

The IDEF0 models should help other users of this process understand and apply a tailored version to their program. Because the IDEF0 Model and the ICOM language is standardized and easily understood, its use in this application is appropriate. Additionally, these models show how the process works in progressively higher levels of detail which helps to ensure that the decision maker understands the process and the user is able to execute the process regardless of the shipyard. This author has used it and the results shown in Table 1 provide evidence of effectiveness.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Over the next five years, the Navy plans to add an additional 46 ships to the fleet (DoN 2018, 9). The planned output of new ships increases by 30%, but the budget over the next five is only planned to increase by about 20% (DoN 2018, 9). It is clear that the shipbuilding program offices are going to need to do more with less money. This study lays out an approach to change management that will help the shipbuilding program offices get the required changes to the ships for less money.

This study analyzed a heuristics based systems approach to managing low-scope growth-work in new construction shipbuilding employed by the author during the construction of a new naval ship. The added cost of delaying certain growth-work can dramatically increase the cost required to perform the work. This is not the case with all growth-work. Some growth-work will cost about the same regardless of the timing of its execution. This study provides an approach to analyzing when to execute the known growth-work, so that it gets executed when it is most cost-effective and least disruptive to the crew.

As the ship progresses through the construction cycle, changes to the ship become steadily more complex. Again, the Shipbuilder's "1-3-8" rule of thumb, says that "work that takes 1 hour to complete in a workshop, takes 3 hours to complete once the steel panels have been welded into units (sometimes called modules), and 8 hours to complete after a block has been erected or after the ship has been launched" (Martin 2010, 7). Once the ship is complete, changes take even more time to complete. This was seen in Chapter II, where the cost to move something as simple as a few clips on the deck cost over $22K more after the ship was complete.

When analyzing when to perform growth-work, the analysis needs to look at both the monetary cost and the disruption to the crew. When the right growth-work is targeted for completion early in construction, the warfighter is able to focus more time on the training and certification after CMA and before sail away. Additionally, because fewer systems will need to be taken down to conduct work, this allows the crew to continue to operate and train on systems in preparation for the certifications required in order to be allowed sail the ship to home port.

In order to be able to analyze quickly a large number of known growth-work items, heuristics were used to analyze the known growth-work early in the construction schedule of a ship. This resulted in a plan that would execute the known growth-work when it was the most cost effective and least disruptive to the crew. The team executed the plan and saved the program office over $1.7 Million on 69 changes with identical scope as the previous ship. The impact of this benefit to the crew is hard to quantify, but by applying critical thought and studying the results discussed previously, making crew disruption part of the formula can only help increase the crew's readiness to certify and ultimately safely sail away.

In order for this approach to be used by other shipbuilding program and project offices, the approach was modeled. The IDEF0 models should help other users of this process understand and apply a tailored version to their program. Because the IDEF0 Model and the ICOM language is standardized and easily understood, its use in this application is appropriate. Additionally, because these models show how the process works in progressively higher levels of detail, this will help to ensure that the decision maker understands the process, and the user can execute the process regardless of which shipyard is using the process.

This study has the benefit of real world results. The application of this heuristics based systems approach to low-scope change management in new construction shipbuilding has decreased both cost and disruption to the crew of one ship. Going forward, this approach needs to be applied to other shipbuilding programs and further refined by experts in the field.

B. CONCLUSIONS AND FUTURE WORK

The goal of this study was to analyze a heuristics based systems approach to managing low-scope growth-work in new construction shipbuilding employed by the author during construction of new naval ship. During this analysis, this study answered or partially answered the research questions contained in Chapter I. The following is a summary of the results.

1. What is the best way to identify and execute low-scope growth-work in new construction shipbuilding?

This study compared the results of identical changes on two different Navy ships. The ship that used the heuristics based systems approach to managing low-scope growth-work in new construction shipbuilding was able to decrease cost to the program office and disruption to the crew. The results suggest that a heuristics-based approach is a better way of identifying and executing low-scope growth-work in new construction shipbuilding. An analysis of all the new construction program offices should be conducted to understand if a heuristics-based approach is in fact the best way to manage low-scope growth work.

2. Can heuristics be used effectively to identify which changes should be executed early in construction and which changes can be completed after completion? If so, what are the right heuristics to use?

This study has shown that heuristics can be used to effectively identify which changes should be executed early in construction and which changes can be completed after completion of the ship. The heuristics used by the author and his team follow.

1. Focus on Hot-work

Hot-work is any operation conducted that produces enough heat burn paint and includes welding, grinding, and plasma cutting. Hot-work can impact multiple compartments and drive cost up if completed after the compartment is completed.

2. Ensure the Systems Work

Growth-work items that affect one of the many ship's systems must be targeted for completion at the appropriate time. Unlike hot-work items, growth-work affecting a system may not need to be executed early in construction, but must be planned for the completion prior to that system being ready for testing.

3. Identify Disruptive Changes

After delivery, the crew's mission is to get certified to operate the ship. The program office and project office, must critically look at each growth-work item and access its impact to the crew.

4. Stay Away from the Captain

The commanding officer, executive officer, and department heads of a new ship and a new crew have limitless things about which to worry. Do not postpone any work item that will directly affect the key leaders of the ship after delivery.

5. Help the Shipbuilder

The shipbuilder is going to build the ship to the specifications that are in the contract. If the contract is missing a key requirement that is either going to impact their INSURV score or make them look bad in the eyes of the crew or the fleet, execute the work early in construction.

These heuristics were effective at both decreasing cost and decreasing disruption to the crew. However, this study does not conclude that these are all the heuristics to use. Further analysis, after the implementation of this process by other program offices and SUPSHIP project offices, needs to be conducted to validate or improve the list of heuristics needed to most effectively employ this process

1. What are the constraints to completion of growth-work during the period of performance of the construction contract?

The major constraint that can be controlled by the Navy is policy. NAVSEAINST 4130.12B provides the guidance to be used when changing the configuration of the ship. The process laid out in this study separates the physical work on the ship form the ILS updates. A conscious decision was made not to use the formal ECP process and to wait until after delivery of the ship to update the ILS products. This decreases the overall cost of the work. While this is allowed by policy, it is not the normal way of conducting business and is not laid out succinctly in the guidance. In the author's experience, the lack of clear guidance and a laid out process causes some decision makers to want to postpone work until the whole job can be done at once. As proven in this study, waiting to accomplish growth-work until after delivery drives cost and increases disruption to the crew. Updated guidance needs to be issued to account for the changes that while necessary, do not require the added cost and engineering effort of an ECP.

The other major constraint is the shipbuilder's policy. In the author's experience, the shipbuilder has generic policies on what changes they will and will not accept. They are sometimes in the form of dollar value thresholds that they cannot exceed. The program office and the SUPSHIP project office can plan for work to be done early in construction, but the shipbuilder does not have to accept the work if it is not a formal ECP. A close relationship with the shipbuilder is needed in order to relax this constraint. Helping the shipbuilder to understand that acceptance of the work early is in their best interest can be difficult, but needs to be done.

2. What data needs to be captured and analyzed to prove the improved process works?

This study partially answered this question. Cost data must be captured from hull to hull in order to allow for a direct comparison for validation. This can be difficult because changes are not always identical hull to hull. In the case study laid out in this thesis, a direct comparison could be made between 69 changes, but there were over 150 changes made prior to the delivery of the second ship. The data captured from those 69 changes proved that the improved process worked. Further research on how to quantitatively assess disruption to the crew needs to be completed. This study provided qualitative data only that would suggest a marked decrease in disruption to the crew.

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